# Settlement and recruitment patterns of Mytilus galloprovincialis L. in the Ría de Ares-Betanzos (NW Spain) in the years 2004/2005

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Abstract

The present study explores the settlement and recruitment capacity of *Mytilus galloprovincialis* L. on artificial collectors in the Ría de Ares-Betanzos (Galicia, NW Spain) in 2004 and 2005 following standard industrial techniques. Three locations in the ría (Arnela, Redes and Miranda) were selected to investigate larvae settlement after the main spawning event (July 2004/2005). Assessment of the recruitment capacity was performed in autumn (September 2004/2005) when mussel seed is usually gathered from the collector ropes and introduced into industrial cultivation at low densities. For both years, the highest settlement densities were recorded at the most seaward location, Miranda. Differences in settlement densities between locations are discussed in terms of the water circulation regime in the ría and the local hydrographic conditions. In 2004, statistical differences in post-settlement mortality resulted in similar recruitment densities at Arnela and Miranda, which were higher than at Redes. In 2005, recruitment densities in Redes and Arnela could not be assessed because predators (*Spondyliosoma cantharus* L.) eliminated the settled population at these locations. Site-specific differences in recruitment density may be attributed to the environmental limitations of each location as well as intra-specific competition.

Keywords: artificial spat collector, mussel, *Mytilus galloprovincialis*, recruitment pattern, settlement pattern

## Introduction

The supply of mussel seed is critical for the development of industrial mussel cultivation (Fuentes & Molares 1994). Worldwide mussel cultivation has traditionally been located in areas where mussel spat are readily available (Mason 1976; Pérez-Camacho & Labarta 2004). The mussel farming industry (*Mytilus galloprovincialis*) in Galicia requires, according to Pérez-Camacho, Labarta and Beiras (1995), approximately 7500 tonnes of mussel seed per year to support an annual mussel production of 200 000 tonnes. According to Labarta (2004), the current production is around 250 000 tonnes year$^{-1}$ (second highest global producer), requiring 9000 tonnes of seed.

Mussel seed is normally obtained directly from intertidal exposed rocky shores or from collector ropes hung during spring when the highest spawning event occurs in the ría (Pérez-Camacho, González & Fuentes 1991). Although seed gathering from shorelines is the method mostly used by farmers (66% of mussel seed used), several studies recommend the use of mussel seed from artificial collectors due to their higher growth rate (Pérez-Camacho et al. 1995; Babarro, Fernández-Reiriz & Labarta 2000; Babarro, Labarta & Fernández-Reiriz 2003). In conjunction with the difficulties of seed acquirement from intertidal rocky shores and the increasing demand for cultivation, it is not surprising that the use of artificial collectors has increased in recent years (Fuentes & Molares 1994; Pérez-Camacho & Labarta 2004).

Nonetheless, the use of collector ropes is not widespread among mussel farmers due to the unpredictability of mussel settlement in the rías (Fuentes & Molares 1994). The spatial and temporal variability of larval settlement has been attributed to several biotic and abiotic factors involved in larval dispersion and settlement. Among the biotic factors, the timing and magnitude of larval supplies (Cáceres-Martínez & Figueras 1998; Porri, McQuaid & Radloff 2006a), the presence of individuals of the same species (Tumanda, Yap, McManus, Ingles & López1997), algal coverage (Hunt & Scheibling 1996; O'Connor, Crowe & McGrath 2006) and microbial coverage (Hunt & Scheibling 1996) are notable. Important abiotic factors include the local hydrographic regimes involved in nutrient and larval dispersion (Eyster & Pechenik 1987; Pulfrich 1996; Cáceres-Martínez & Figueras 1998; Dobretsov & Miron 2001; Pernet, Tremblay & Bourget 2003; Porri et al. 2006a), physico-chemical substratum properties (Pulfrich 1996; Alfaro, Copp, Appleton, Kelly & Jeffs 2006), temperature (Pineda 1991; Garland, Zimmer & Lentz 2002), daylight and orientation (Bayne1964).

In addition to the high variability of larval settlement, defined as the point when an individual first takes up permanent residence on the substratum (Connell1985), several factors contribute to the variability of post-settlement mortality and, therefore, recruitment, defined as the recently settled juveniles that have survived for a period of time after settlement (Connell 1985). Hunt and Scheibling (1997) described causes of post-settlement mortality, such as delays in metamorphosis, biological disturbance, physical disturbance and hydrodynamics, physiological stress, predation or competition for space and food. The interaction between settlement and post-settlement mortality determines the number of viable individuals that can be introduced into industrial cultivation.

Monitoring larval settlement and recruitment in both natural and artificial substrata is an important tool for assessing the population dynamics of commercial species (Petraitis 1991; Cáceres-Martínez, Robledo & Figueras

1993; Fuentes & Molares 1994; Pulfrich 1996; Cáceres-Martínez & Figueras 1998; Jeffs, Holland, Hooker & Hayden 1999; Ramírez & Cáceres-Martínez 1999; Porri *et al*. 2006a; Porri, McQuaid & Radloff 2006b). In the present study, we assessed both settlement and recruitment of *M. galloprovincialis* in three culture locations in the Ría de Ares-Betanzos (Arnela, Redes and Miranda) during spring-autumn of 2004 and 2005 following industrial cultivation procedures.

## Material and methods

### Experimental design

The three locations dedicated to industrial seed collection in Ría de Ares-Betanzos (Arnela, Redes and Miranda; Fig. 1) were selected to assess larval settlement and recruitment on artificial substratum. Figure 1 shows the location of Lorbé, where most of the mussel culture in the ría is concentrated, although not commonly used as a mussel seed collection area.

In February 2004, three 6m (2.5 cm of diameter) nylon ropes, the traditional material for mussel seed collection, were placed at each location. An initial Sampling was carried out in July 2004 to evaluate larval settlement when the seed length was manageable. A final sampling in September 2004 was carried out to evaluate recruitment and perform ‘early thinning-out’, whereby the mussels were detached from collection ropes and cultivated at lower densities in industrial cultivation.

The experimental design was repeated on the same dates in 2005 to assess temporal variability in settlement and recruitment in the ría. In late July 2005, the monitoring of Arnela and Redes collection areas was terminated because predators (Spondyliosoma cantharus) eliminated the settled population.

## Mussel sampling

For each rope and location, two replicates were sampled from 3 to 4mwater depth, whereby all individuals were removed from a10 cm length section of the rope. The density of the mussels was estimated by counting, and individual mussel length was recorded using callipers (Mitutoyo®, Mitutoyo Corporation, Kanagawa, Japan). The length was defined as the maximum measurement to the nearest 0.1mmalong the anterior-posterior axis. Then, the samples were separated into 1mm length classes. The adjusted shell length was calculated with the formula: $L=\Sigma(CL \times F) \times N^{-1}$ (Box, Hunter & Hunter 1989), where $L$ is the adjusted shell length, $CL$ is the individual length class, $F$ is the frequency in each length class and $N$ is the total number of individuals.

## Data analysis

The effect of location (Arnela, Redes and Miranda) and sampling (settlement and recruitment) on the density and adjusted length of mussel seed in 2004 were tested using a two-way ANOVA and Tukey's test as a post hoc test.

Growth rates (GR) were calculated for the year 2004 between sampling times (July 2004/September 2004) with the formula: $GR=(AL_t-AL_0)/(T_t-T_0)$, where $AL_t$ and $AL_0$ are the adjusted shell length at the final and initial sampling times, respectively, and $(T_t-T_0)$ represents the time between experimental sampling in days. One-way ANOVA was used to compare the growth rates of mussel seed collector locations, and Tukey's test was used as a post hoc test.

The instantaneous total mortality coefficient ($Z$) was calculated for the year 2004 during the sampling time interval (July 2004/September 2004) using the expression: $Nt=N_0\ e^{-zt}$ where $N_0$ and $N_t$ are the numbers of mussels per metre of rope at the beginning and the end of the sampling interval ($t$) expressed in days. One-way ANOVA was used to compare the mortality coefficients of mussel seed collector locations, and Tukey's test was used as a post hoc test.

For 2005, settlement densities and adjusted lengths were compared between locations (Arnela, Redes and Miranda) using a one-way ANOVA and Tukey's test as a post hoc test. Settlement densities were compared between 2004 and 2005 using one way ANOVA, whereas adjusted lengths in settlement were compared between years using Kruskal-Wallis test because Levene's test showed no homogeneity of Variance. All data analysis was carried out using the statistical package SPSS 13.0.

## Results

Settlement and recruitment-adjusted shell lengths and densities for the three locations in 2004 are shown in Table 1. Two-way ANOVA (Table 2) results showed a significant effect of location (Arnela, Redes and Miranda) and sampling (settlement and recruitment) on density, as well as the interaction of both factors. This implies a differential evolution of density with time between the locations.

Because of the significant interaction between factors, one-way ANOVA (Table 3) for each sampling is used to assess the effect of location on density. The *post hoc* test shows a significantly higher settlement density on the collector ropes from Miranda (12517 ± 923 ind.$m^{-1}$) than for the other locations, where densities are similar (Redes 8526 ± 1117 ind.$m^{-1}$ and Arnela 8495 ± 1075 ind. $M^{-1}$). With regard to recruitment, the *post hoc* test shows similar densities for collector ropes from Miranda (5009 ± 907 ind.$m^{-1}$) and Arnela (4869 ± 529 ind. $m^{-1}$), although both display higher densities than Redes (3079 ± 561ind.$m^{-1}$). Differences in the instantaneous mortality coefficient between populations (ANOVA; Table 4) engender differences between settlement and recruitment density. Tukey's test analysis of instantaneous mortality coefficients between locations reveals a significantly lower mortality in Arnela (0.007 ± 0.0002 day$^{-1}$) compared with Miranda (0.012 ± 0.0030 day$^{-1}$) and Redes (0.013 ± 0.0041day$^{-1}$) (ANOVA; Table 4).

With regard to the adjusted length (Table 1), two-way ANOVA (Table 2) shows a significant effect of location and sampling. However, the interaction between these factors shows no significant effect, which indicates that growth rates follow a similar pattern at each location (0.25 ± 0.019, 0.23 ± 0.001 and 0.21 ± 0.021mmday$^{-1}$ for Miranda, Arnela and Redes respectively) as confirmed by ANOVA (Table 4). The post hoc test shows a higher adjusted length for individuals from Redes compared with Miranda and Arnela, which are statistically identical (Table 2).

A similar monitoring design on settlement and recruitment assessment was carried out in 2005, although predation (S. cantharus) prevented assessment of the recruitment in Arnela and Redes. The mean adjusted shell length and density for settlement and recruitment (only for Miranda) are shown in Table 1. One-way ANOVA (Table 5) shows a significant effect of location on settlement density. The post hoc test shows a significantly higher density on collector ropes from Miranda (33097 ± 3155 ind. M$^{-1}$) compared with Redes (11912 ± 1712 ind. M$^{-1}$) and Arnela (9982 ± 1401ind. M$^{-1}$), which show no signify cant differences between them. With regard to the adjusted length, one-way ANOVA (Table 5) alludes to a significant effect of location. The *post hoc* test shows a significantly higher adjusted shell length for mussel seed collected in Redes (7.0 ± 0.34mm) than Arnela (6.3 ± 0.21mm) and Miranda (6.2 ± 0.20mm), which show similar adjusted shell lengths.

A similar spatial pattern is observed for the interannual comparisons in settlement density, although in quantitative terms, 2005 shows significantly higher densities than 2004 for Miranda ($n$=6, $F_{5,1}$=117.61, $P$<0.001).With respect to the adjusted shell length, a similar spatial pattern is observed for both years in settlement. However, the adjusted shell length in 2005 is significantly lower than in 2004 for all locations ($n$=18, $\chi^2$=12.79, d.f.=1, $P$<0.001).

## Discussion

### Larval settlement

In the present study, differences in larval settlement densities are observed between the locations under study, with the greatest settlement density for 2004 and 2005 at Miranda. Spatial and temporal differences in larval settlement between nearby locations have been extensively documented and attributed to several biotic and abiotic factors (see ‘Introduction’). The observed spatial differences may be primarily attributed to the local hydrographic conditions because the settlement monitoring design was identical and simultaneous in each location of the ría.

Mollusc larvae possess certain capacity to select their habitat actively (Snodden & Roberts 1997; Dobretsov&Miron2001; Shanks&Brink2005), which is limited by slow swimming velocities. Thus, the local oceanographic conditions are the principal agent in larval dispersion (Alfaro & Jeffs 2003; Pernet et al. 2003; Porri et al. 2006a). In the case of the Galician rias, apart from the contribution of tidal currents, the subtidal circulation generated by local and coastal winds and continental runoff, control the dynamics of these coastal embayments (Fraga 1996). Since mussel fattening areas in Ría de Ares-Betanzos are concentrated along the southern shore of the ría (Lorbé & Amela), it is hypothesized that the subtidal circulation should transport larvae and planktonic postlarvae towards the northern shore (Redes & Miranda) as suggested for the Ría de Vigo by Caceres- Martinez & Figueras (1998). Such a circulation pattern is specially in our study area under dominant southeasterly wind conditions. In addition, several studies have observed greater larval settlement densities in areas where current velocities and turbulence are higher, both in the field (Pulfrich 1996; Cáceres-Martínez & Figueras1998) and in the laboratory (Eyster & Pechenik 1987; Pernet et al. 2003; Alfaro 2005, 2006a). In the Ría de Ares-Betanzos, Miranda is located in the most seaward area and characterized by high current velocities (unpublished results), and here greater settlement densities were recorded in both years. Other studies in the Galician rías also reported the highest settlement densities at the most seaward location (Ría de Arousa: Fuentes & Molares 1994; Ría deVigo: Cáceres-Martínez & Figueras1998).

In addition to spatial settlement densities, differences in the adjusted length of mussel seed are recorded between locations. The population at Redes shows a significantly higher settlement-adjusted length than the other populations under study for 2004 and 2005. These differences in initial adjusted shell length cannot be attributed to differences in growth capacity because similar growth rate values are recorded for the three locations. Petraitis (1991) noticed that individuals settled in sheltered areas showed significantly higher lengths than those settled in more exposed areas. Snodden and Roberts (1997) observed similar tendencies and suggested that water movement may affect primary (larvae of shell length<0.415mm) and secondary settlers (larvae of shell length>0.415mm) differently. Our study results show that the sheltered location of the ría, Redes, recorded the highest adjusted shell length values in both years.

Although settlement trends between locations are similar for both years, Miranda is characterized by a significantly higher settlement in 2005. Moreover, the lower adjusted shell length values recorded in 2005 for each location could be caused by a delay in larval settlement. Changes in the magnitude and seasonality of spawning (Cáceres-Martínez & Figueras 1998; Porri et al. 2006a), delays in metamorphosis (Bayne 1965; Seed & Suchanek 1992) or the interaction between several environmental factors (changes in temperature, food availability or hydrographic conditions) may explain the interannual settlement variability.

## Recruitment

The interaction between larval settlement and early post-settlement mortality determines the extent of larval recruitment. The natural phenomenon of self-thinning during high-density growth is one of the main causes of post-settlement mortality (Kautsky 1982; Connell 1985; Hunt & Scheibling 1997; Guiñez & Castilla1999; Alunno-Bruscia, Petraitis, Bourget & Fréchette 2000; Guiñez 2005). In this way, recruitment density would reflect settlement only in the absence of environmental restrictions (Hunt & Scheibling 1997). The results of 2004 highlight the importance of local environmental restrictions, as indicated by the observed differences in instantaneous mortality coefficients between Redes and Arnela, which showed similar settlement densities. Local environmental limitations, such as hydrography (Hunt & Scheibling 1997; McQuaid, Lindsay & Lindsay 2000), food availability (Hunt & Scheibling 1997; Alfaro 2006b) or predation rates, could also contribute to the regulation of the mortality rate and, therefore, recruitment density. The results from 2005 support the importance of the local environment, because predators (*S. cantharus*) eliminated the settled population at Arnela and Redes. Fish predation on mollusc seed has been extensively documented (Osman & Whitlatch 1998; Denny & Schiel 2001; Crooks 2002; Pita, Gamito & Erzini 2002; Bartsch, Bartsch & Gutreuter 2005; Rilov & Schiel 2006) and is a major cause of mussel seed mortality in industrial cultivation (Schiel 2004; Morrisey, Cole, Davey, Handley, Bradley, Brown & Madarasz 2006).

In summary, from an ecological point of view, the differences observed in settlement between the three study locations may be primarily attributed to water circulation pattern and the local environmental conditions. The same spatial tendencies are not observed in the recruitment trends. Therefore, recruitment is not only influenced by settlement but also by the interaction between local environmental constraints (biological and physical) and the intra-specific competition associated with these limitations. With regard to industrial production, the most seaward location is the best area for mussel seed collection. Although the recruitment density here is similar to other areas, fish predation was not registered.

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Figure 1 Map of the Ría de Ares-Betanzos, showing the three monitored mussel seed collection areas (Arnela, Redes and Miranda) and the fattening areas (Lorbé and Arnela).

Table 1 Adjusted shell length (mm) and density (ind.m$^{-1}$) in settlement and recruitment for the study locations in 2004 and 2005

Table 2 Two-way ANOVAs to determine the effect of location (Arnela, Redes and Miranda) and sampling (settlement and recruitment) on density and adjusted length in 2004

Table 3 One-way ANOVAs to determine the effect of location (Arnela, Redes and Miranda) on settlement and recruitment densities in 2004

Table 4 ANOVAs to determine the effect of location (Arnela, Redes and Miranda) on instantaneous mortality coefficients and growth rates in 2004

Table 5 One-way ANOVAs to determine the effect of location (Arnela, Redes and Miranda) on the settlement density and settlement-adjusted shell length in 2005

Figure 1

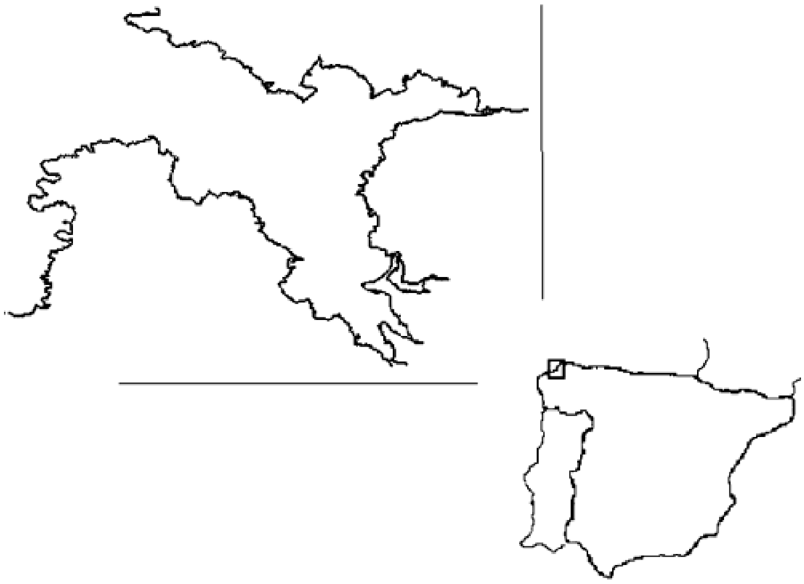

Table 1

| Year | Sampling | Location | Adjusted shell length (mm) | Density (ind.m$^{-1}$) |
|---|---|---|---|---|
| 2004 | Settlement | Arnela | 14.2 ± 0.57 | 8495 ± 1075 |
| | | Redes | 17.6 ± 0.39 | 8526 ± 1117 |
| | | Miranda | 13.4 ± 0.10 | 12 517 ± 923 |
| | Recruitment | Arnela | 32.3 ± 0.56 | 4869 ± 529 |
| | | Redes | 34.1 ± 2.01 | 3079 ± 561 |
| | | Miranda | 33.1 ± 1.35 | 5009 ± 907 |
| 2005 | Settlement | Arnela | 6.3 ± 0.21 | 9982 ± 1401 |
| | | Redes | 7.0 ± 0.34 11 | 912 ± 1712 |
| | | Miranda | 6.2 ± 0.20 | 33 097 ± 3155 |
| | Recruitment | Arnela | | |
| | | Redes | | |
| | | Miranda | 25.1 ± 1.30 | 12 730 ± 510 |

Table2

| Sources of variation | d.f. | SS | MS | *F value* | *P* |
|---|---|---|---|---|---|
| Density | | | | | |
| Location | 2 | 27 740 336.3 | 13 870 168.2 | 17.82 | <0.001 |
| Sampling | 1 | 137 459 896.8 | 137 459 897.0 | 176.58 | <0.001 |
| Interaction | 2 | 11 319 000.6 | 5 659 500.3 | 7.27 | <0.01 |
| Adjusted length | | | | | |
| Location | 2 | 27.0 | 13.5 | 12.17 | <0.001 |
| Sampling | 1 | 1480.1 | 1480.1 | 1333.74 | <0.001 |
| Interaction | 2 | 7.4 | 3.7 | 3.33 | 0.071 |

Table 3

| Source of variation | d.f. | SS | MS | *F value* | *P* |
|---|---|---|---|---|---|
| Settlement | | | | | |
| Location | 2 | 32 113 233.6 | 16 056 616.8 | 14.80 | <0.01 |
| Recruitment | | | | | |
| Location | 2 | 6 946 103.354 | 3 473 051.68 | 7.357 | <0.05 |

Table 4

| Source of variation | d.f. | SS | MS | *F value* | *P* |
|---|---|---|---|---|---|
| Mortality coefficient | | | | | |
| Location | 2 | 0.0003 | 0.0002 | 8.20 | <0.05 |
| Growth rate | | | | | |
| Location | 2 | 0.0024 | 0.0012 | 4.69 | 0.059 |

Table 5

| Source of | d.f. | SS | MS | *F value* | *P* |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **variation** | | | | | |
| Density | | | | | |
| Location | 2 | 986 868 694.7 | 493 434 347.0 | 99.70 | <0.001 |
| Adjusted length | | | | | |
| Location | 2 | 29.3 | 14.7 | 90.65 | <0.001 |